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EXPORT COEFFICIENTS VARIABILITY ANALYSIS ON NONPOINT POLLUTION MODELING

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Abstract: All over the world, there has been a major concern about pollution on surface waters. point sources pollutants (from sewage treatment plants, industrial releases, etc.) are easily recogzinable and traceble and frequently the highly contaminant; nonetheless, non-point pollution (surface runoff, forest cutting, fertilizers from crop lands, etc.) are being counted responsible for, sometimes, more than 30% of the total load in surface waters. Thus, it is essential to develop methods to quantify the pollutant loads found in surface flows, to design projects and engineering structures that reduce or prevent nonpoint pollution. Nonpoint loads can be quantified and estimated by several methods, such as: Exports Coefficients (EC) or Unit Loads (UL); Event Mean Concentration (EMC); Mathematical Simulation Models; or even combinations, improving reliability. The general goal of this paper therefore is to provide a framework to estimate the pollutants unit loads and a brief tracking and comparison of how Unit Loads are obtained around the world and its values. Results show that EC are a simple, easy and quick method to predict pollution, although some studies tend to focus a lot on yearly production plus many are not calibrated with observed data. Nevertheless, the regular track of the variability of the EC in the catchment might be the key for planning and managing pollution

Keywords – Nonpoint pollution; export coefficients

INTRODUCTION

All around the world, there has been a major concern about pollution on surface waters. Cities are most responsible for the intensity of the stress on water quality of surface waters, deepening by social and economic activity. In the past, all the technical methods for controlling water pollution were developed around urban problems, not those of intensifying agriculture or silviculture (Beck 2005). Both land uses can carry problems of point and nonpoint pollution sources.

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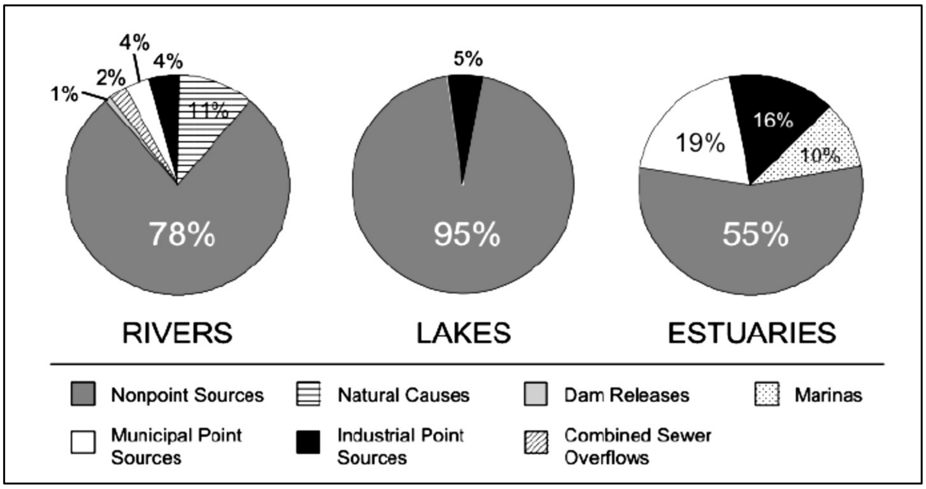
Much is known about point sources pollutants (from sewage treatment plants, industrial releases, etc.), nonetheless, non-point pollution (surface runoff, forest cutting, fertilizers from crop lands, etc.) are being counted responsible for, sometimes, more than 30% of the total load in surface waters, as shown in Figure 1 (MORIHAMA; AMARO; TOMINAGA; YAZAKI et al., 2012), (NOVOTNY, 2002), (MOURA; PELLEGRINO; MARTINS, 2013).

Thus, it is essential to develop methods to quantify the pollutant loads found in surface flows, to design projects and engineering structures that reduce or prevent nonpoint pollution. Some measures for controlling diffuse pollution involve non-structural, administrative, and educational actions. It can be said also that diffuse pollution has cultural aspects that involves more complexes factors as economic and social. That said, the will from the government and the engagement of the citizens in this process is extremely important, discussing exhaustively a problem that involves all departments of society (PARENTI; PEREIRA; FUNARI, 2016).

One of the most used methods to predict pollution (both endemic and diffuse – point and nonpoint) is the Export Coefficients (Unit Loads) Method. All unit loads models, and some complex mechanistic models, rely generally on land use and hydrologic events (or series) to estimate pollutants concentrations and transport in large catchments (Johnes 1996). The general goal of this paper therefore is to provide a framework to estimate the pollutant's unit loads and a brief tracking and comparison of how Unit Loads are obtained around the world and its values.

Figure 1 - Causes of water quality impairment in Georgia (USA). Source: Minnesota Stormwater Manual, 2020.



NONPOINT POLLUTION MODELLING

Nonpoint pollution is a process that begins with washing and transporting air pollutants through rain, the formation of surface flow that carry a large part of the pollutants deposited on the catchment surface and transport to their destination in a receiving body. This type of dumping, unlike occasional releases, is a random phenomenon that is difficult to measure and whose magnitudes depend mainly on meteorological factors and the type of land use and occupation (Righetto, Gomes et al. 2017).

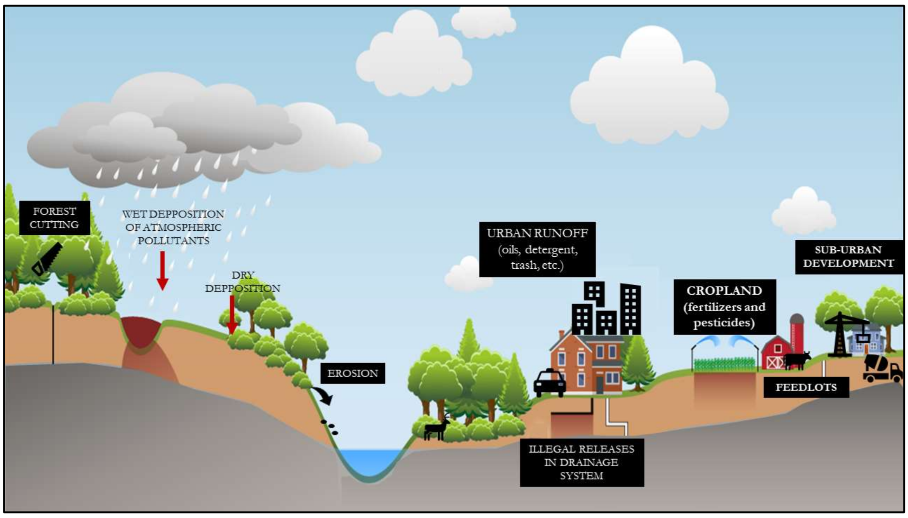
The most striking feature of diffuse (nonpoint) pollution is the great variability of the pollutants concentration available on the surfaces captured by runoff. Resulting concentrations in water vary by orders of magnitude between river basins, between different precipitation events, and also over the same event (Baptista, Nascimento et al. 2005).

Unlike sewage, which goes to treatment plants for contaminant removal, polluted stormwater runoff flows untreated into stormwater drainage where it is carried to the nearest stream, river, lake, estuary, or coastal water. Figure 2 presents some major sources of stormwater pollution (NPS pollution).This type of water pollution might seem to be very small, but cumulatively for a large area or population have a significant impact into surface waters and many times can be the major source of pollution in watersheds (ARC 2016).

EXPORT COEFFICIENTS (EC) MODEL

Loads are the most reliable measure of the effectiveness of watershed management practices. This approach is reflected in the development of the concept of Total Maximum Daily Loads (TMDL) (NOVOTNY 2002). The term TMDL is used to denote the maximum quantity of a pollutant that a water body can assimilate and still meet water quality standards. In a regulatory sense, the term is used to denote a process or project in which the concept of TMDL is applied to improve water quality of impaired water bodies (Borah Deva, Ahmadisharaf et al. 2019).

Figure 2 - NPS pollution sources (Author, 2021)



In the Export Coefficients (EC) or Unit Loads (UL) methods, as its name implies, all runoff is assumed to have the same, constant concentration for a given pollutant. These are simple values or functions that express the generation of pollutants per unit area and time for each type of land use, by the population and their sanitation infrastructure. The most common units of measure are mass / area-time and mass / inhabitants-time.

At its very simplest, an annual runoff volume can be multiplied by a concentration to produce an annual runoff load. However, this option may be coupled with a hydrologic model, wherein loads will vary if the model produces variable flows. This option may be quite useful because it may be used with any hydrologic or hydraulic model to produce loads, merely by multiplying by the constant concentration (NOVOTNY 2002).

This method requires that these coefficients must be "characteristic" of a particular use and occupation of the soil. It is a simple and easy to use practical application. The framework of how these coefficients are obtained are illustrated at Figure 03 adapted from the work of (Shrestha, Kazama et al. 2008).

Plus, the formulation involved is described as it follows. The total affluent load (W) is the sum of the dry weather load (Wts) and the rainfall load (Wec) according to the basic Equation 1.

$$W = W_{ts} + W_{ec} \tag{1}$$

Wts being detailed on Equation 2:

$$W_{ts} = f_t \times \left[\sum_i (A_i c_i) + \sum_j (P_j e_j) + \sum_k (B_k) \right] \quad (2)$$

Wherein:

- f_t is the basin's transport coefficient; representing the processes of retention and self-purification between the generation points and the mouth of the stream that drains the basin;

- A_i is the occupied area by the different categories of land use in the basin, in km^2;

- c_i is the diffusion load coefficient of the different categories of land use, in kg / km^2.day;

- P_j is the urban population resident in the basin, under different conditions of availability of sanitary infrastructure;

- e_j is the export coefficient of sewage generated by population under different conditions availability of sanitary infrastructure, in kg / inhab.day;

- B_k are other point loads in the basin, in kg / day.

And W_{ec} can be calculated by Equation 3.

$$W_{ec} = \sum_i [CME_i \times A_i] \times q \times C_{es} \quad (3)$$

In which:

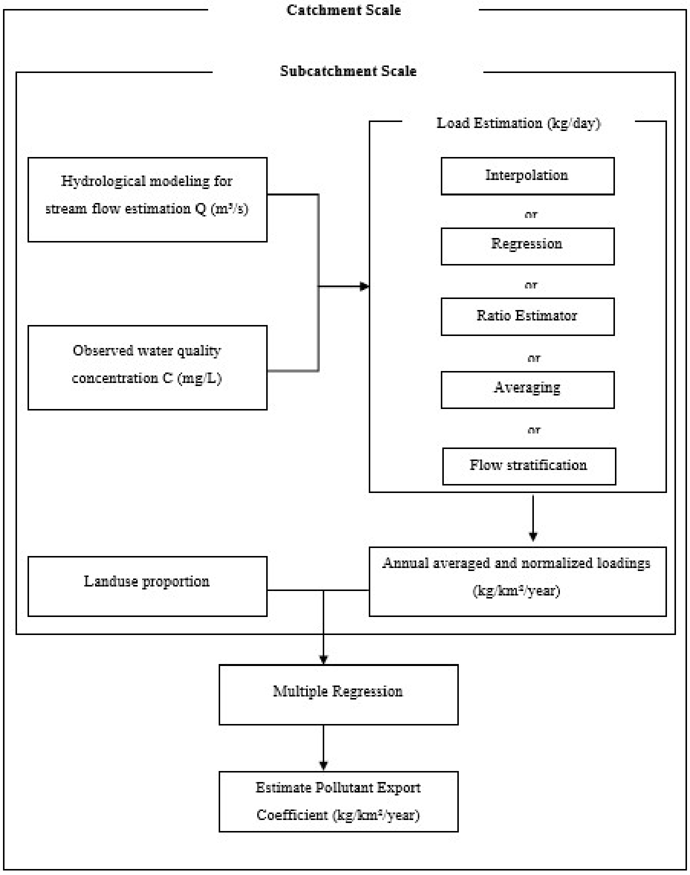
- CME is the typical concentration for each constituent considered in rainfall events (mg/L);

- A_i is the catchment area for each land use category (km²);

- q is the specific long-term average flow of each catchment area (L/s.km²);

- C_{es} is the coefficient of surface runoff (rate between average flow of surface flow and average flow in the basin).

Figure 3 - General framework to estimate pollutant export coefficients from instream monitoring data.



EXPORT COEFFICIENTS WORLDWIDE

There are many works related to the export coefficients obtained from experiments around the world. However, some of them are not framed by land use category and/or occupation type that difficult the comparison among them and avoid their application worldwide. Several works developed in Brazil use the MQUAL (Modelo de Correlação Uso do Solo / Qualidade da Água) model (SMA 1998), as described by Eiger *et al.*(1999) and FCTH and SSRH (2009, 2016), which is a mathematical model that generates nonpoint and point loads of pollutants in a drainage basin. Still, lack of water quality monitored data prevent researchers to calibrate the model and the results represent only potentialities for pollution management actions.

Plus, the constituents focused on many projects vary much by place to place. For instance, on developed countries (like USA), infrastructure is, usually, well stablished and the focus remain on nutrients (phosphorus and nitrogen). On the other side, countries like Brazil have still many flaws in the sewage infrastructure and frequently organic matter (BOD) is the focus.

For this analysis, about 10 works that had enough information were selected to represent different locations around the world. For better understanding also, analysis were separated by land use and constituent focusing on Total Phosphorus, Total Nitrogen and BOD (when available) and some important description on data were added to labels.

Agriculture Land use

The constant increase of population and food scarcity dramatically increased agricultural production and productivity had a major consequence by changing farming practices and by the introduction of agricultural chemicals - fertilizers, herbicides and insecticides which contains mainly phosphorus and nitrogen (Novotny 2005).

Figures 4 and 5 illustrate Export Coefficients for Phosphorus and Nitrogen on several studies. From both Figures one can see that Novotny maximum value were considerably higher than the other works shown. Also, it is possible to observe that export coefficients obtained in wet seasons are higher than in dry seasons, all due the fact that rainfall washes off the nutrients from the watershed surface.

Figure 4 - Export Coefficients for Total Phosphorus for Agriculture Land Use in Kg/km².day

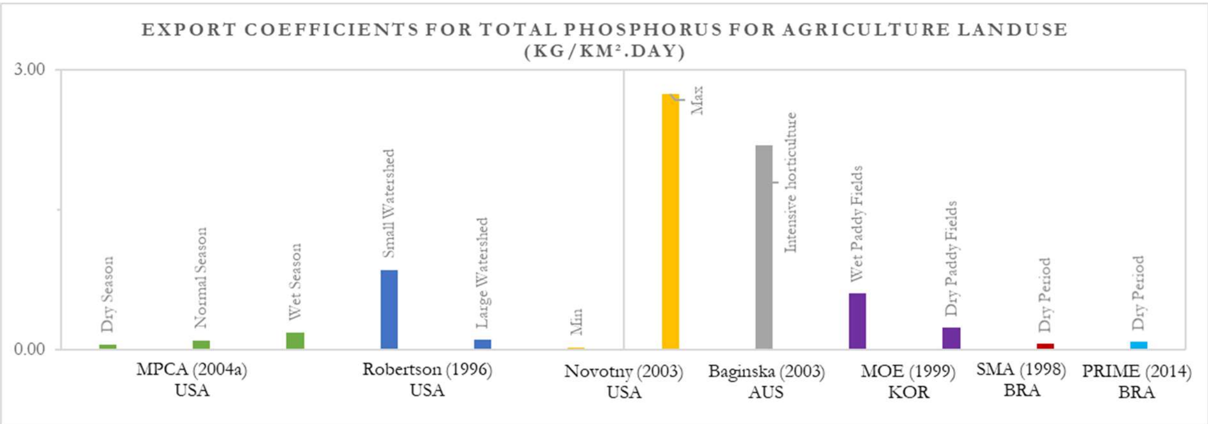
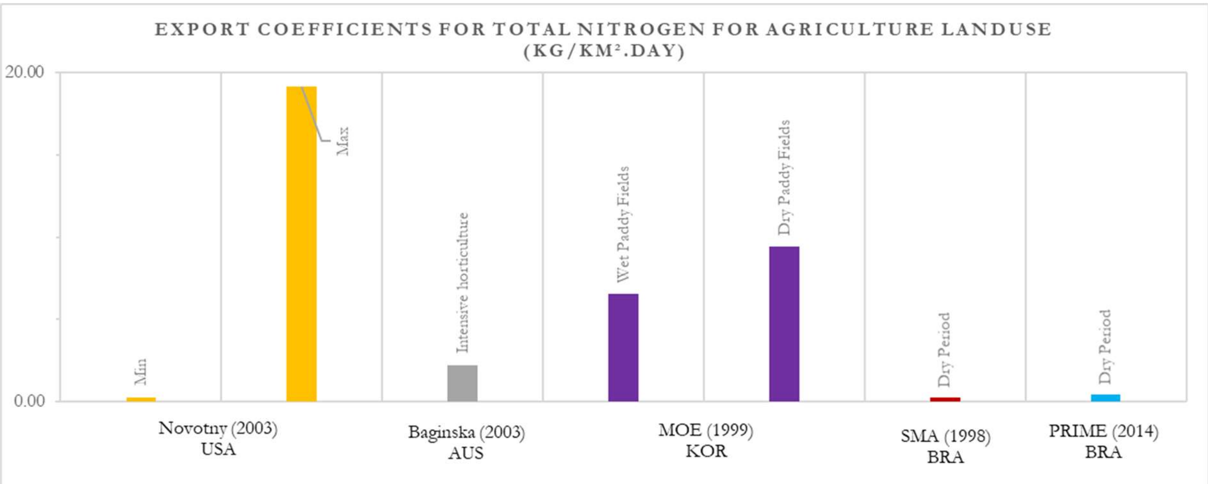
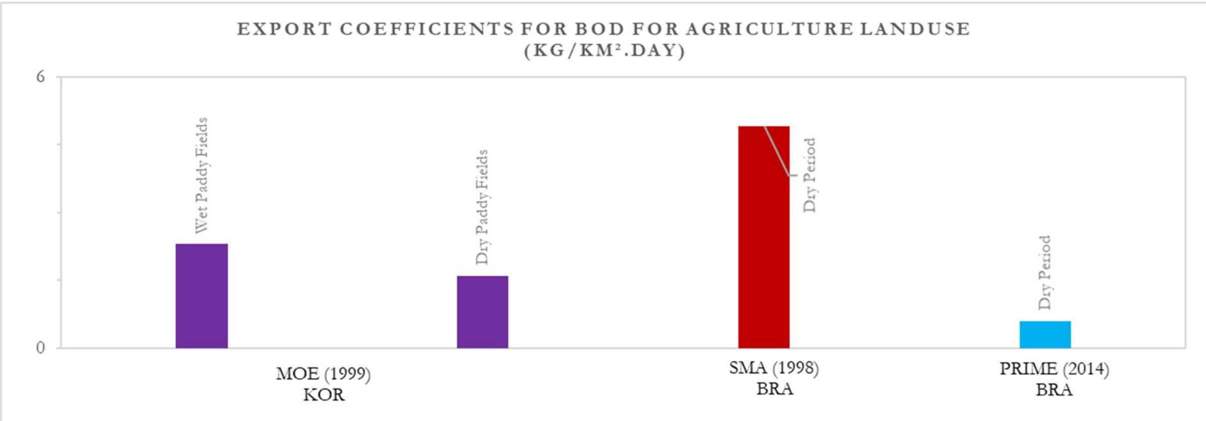


Figure 5 - Export Coefficients for Total Nitrogen for Agriculture Land Use in Kg/km².day



Regarding BOD export coefficients (Figure 6), as mentioned before, there was not information from studies originated in USA and other countries. In fact, this water quality variable has progressively been replaced by other more representative as Total Organic Carbon (TOC). Publications originated from Brazilian and Korean studies point that values are not much different from each other, although BOD are always a very local variable. It is important to remind that in agricultural areas, BOD might come from vegetative organisms and feces from other animals (birds, mammals, etc).

Figure 6 - Export Coefficients for BOD for Agriculture Land Use in Kg/km².day



Urban Land Use

For urban areas, pollution problems tend to be greater from other areas. In cities with separate storm and sanitary sewerage systems, stormwater runoff is the primary degrader of streams (Hatt, Fletcher et al. 2004). Increased imperviousness and drainage systems typical of urban areas, result in increased frequency and intensity of flood flows, decreased groundwater levels, increased stream channel and bank erosion plus increased loads and concentrations of pollutants (Novotny 1994).

Figures 7 and 8 shows EC for Total Phosphorus for urban (residential, commercial, industrial, etc.) land use and Figures 9 and 10 for Total Nitrogen. For better representation, international and national (Brazil) studies were divided. When put together, the results obtained in the study developed by FCTH (2017) were significantly higher from all the others (10 times higher, for some land uses), that can be seen in yellow for national studies.

Figure 7 - Export Coefficients for Total Phosphorus for Urban Land Use – International Studies (Kg/km².day)

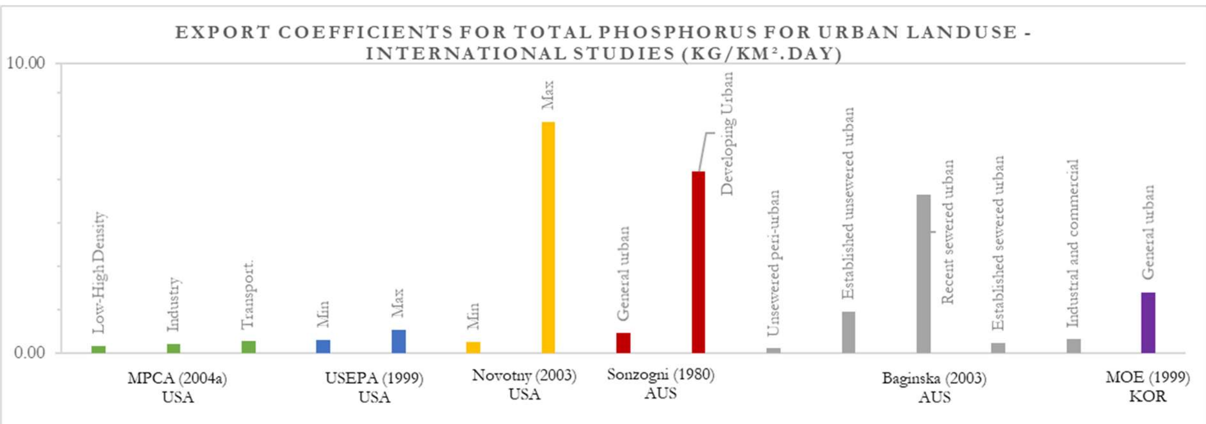


Figure 8 - Export Coefficients for Total Phosphorus for Urban Land Use – National Studies (Kg/km².day)

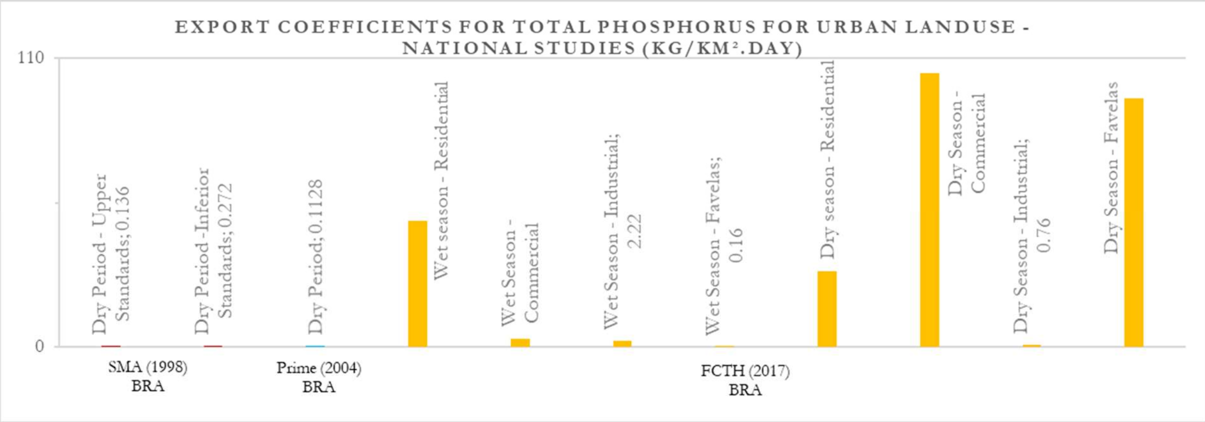


Figure 9 - Export Coefficients for Total Nitrogen for Urban Land Use – International Studies (Kg/km².day)

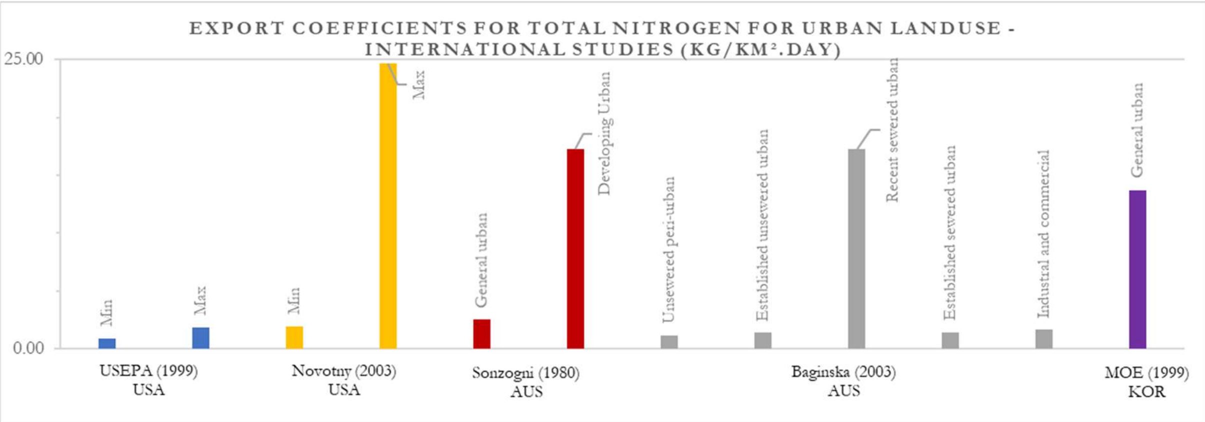
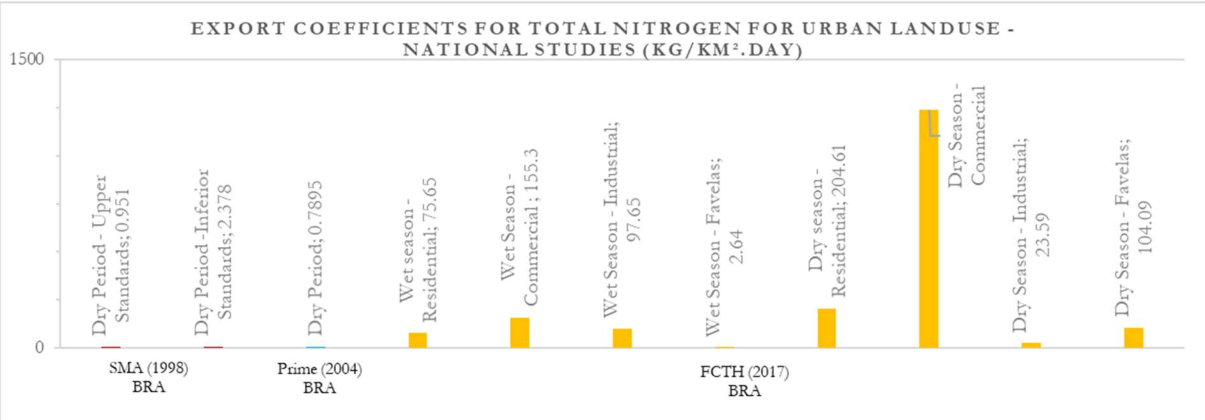
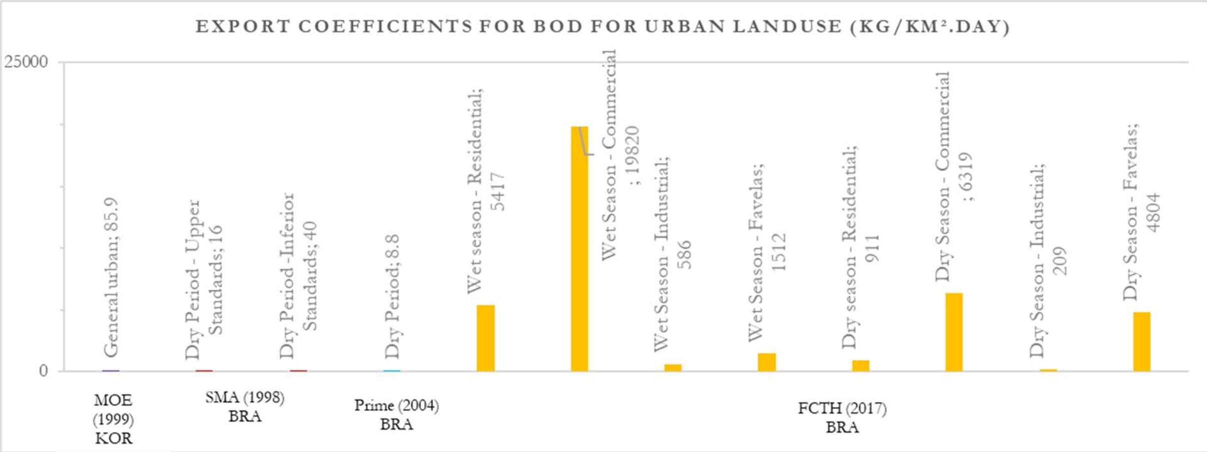


Figure 10 - Export Coefficients for Total Nitrogen for Urban Land Use – National Studies (Kg/km².day)



For BOD this situation is even worse: BOD obtained during Wet Season in commercial areas on the work of FCTH (2017) is 230 higher than from the work of MOE (1999), as seen in Figure 11. This brings out a concerning problem experienced in Brazil, and specially on this study area (Jaguaré – São Paulo): the direct discharges of untreated raw domestic sewage into water bodies. This particular area of São Paulo - the biggest city not only in Brazil but in all Latin America – experiences favelas and unstructured or non-existent sewage systems (nor collected nor treated). Even neglecting this data, one can still find BOD Export Coefficients values around 6000 kg/[km².day].

Figure 11 - Export Coefficients for BOD for Urban Land Use (Kg/km².day)



Forest Land Use

Among potential polluting activities, forestry is responsible for a considerable part, as it increases acidification, DOC (Dissolved Organic Carbon) and sediment production (D'Arcy and Frost 2001). Figures 12, 13 and 14 show EC for Total Phosphorus, Nitrogen and BOD for forested land uses. There are not much information on the results presented by Novotny (2003) and MOE (1999) that showed the highest values observed for TN and TP. Even tough, on average all values are consistently similar.

Figure 12 - Export Coefficients for Total Phosphorus for Forest Land Use (Kg/km².day)

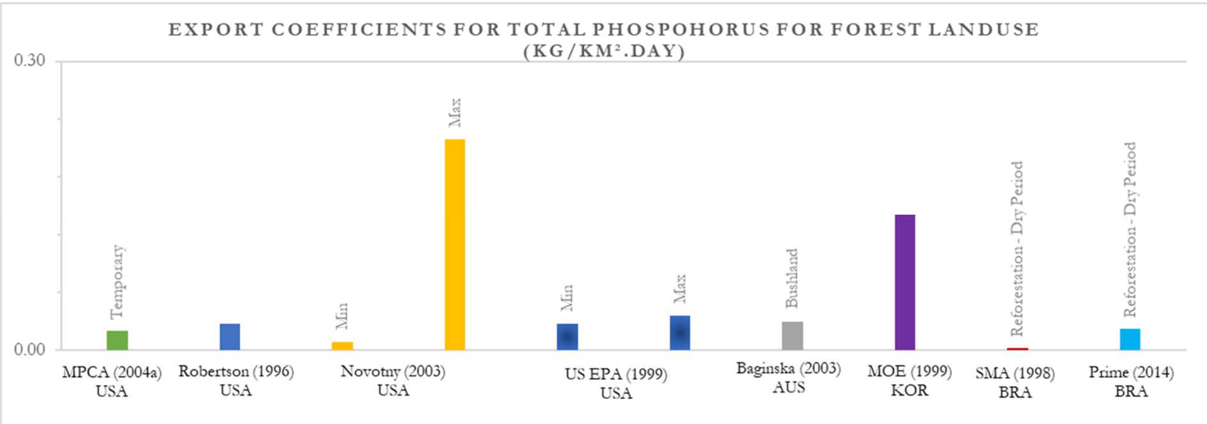


Figure 13 - Export Coefficients for Total Nitrogen for Forest Land Use (Kg/km².day)

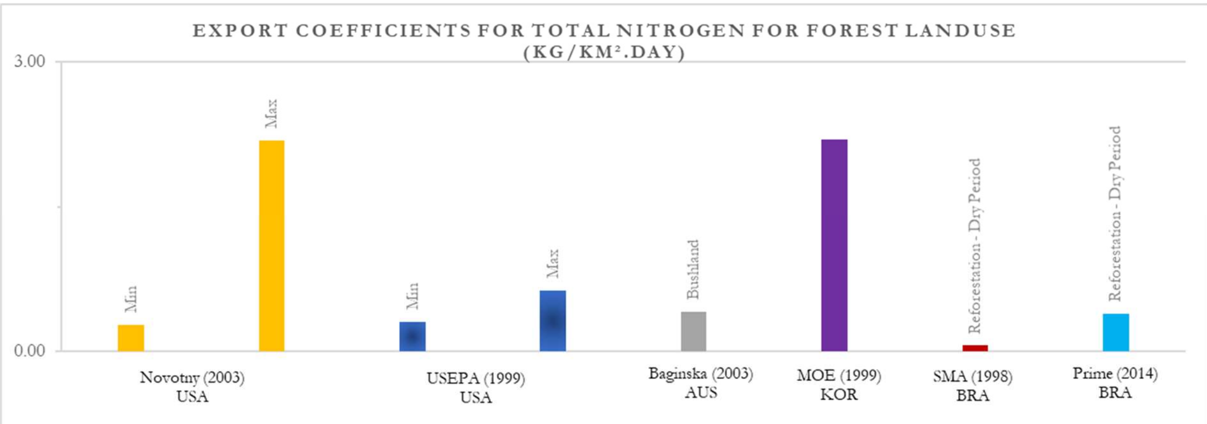
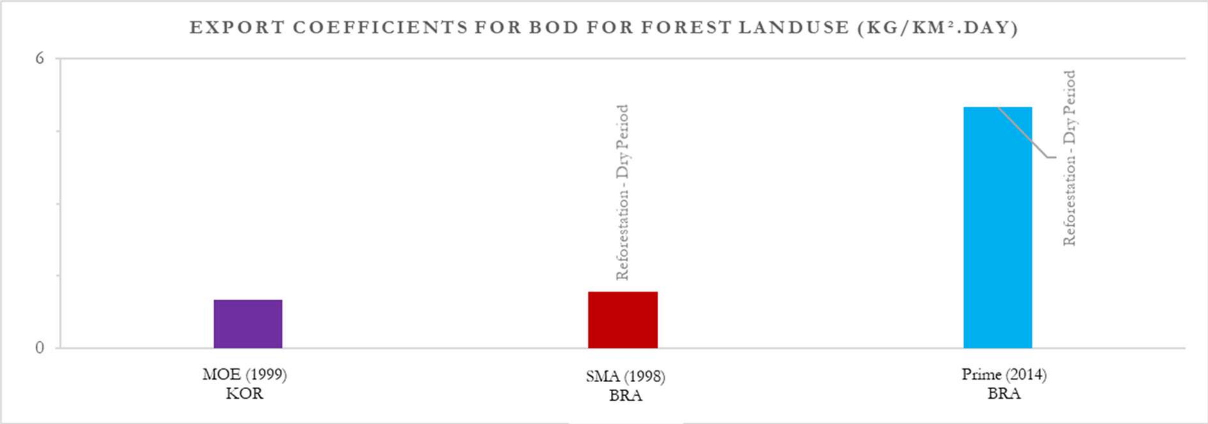


Figure 14 - Export Coefficients for BOD for Forest Land Use (Kg/km².day)



FINAL CONSIDERATIONS

Results show that Export Coefficients (EC) are a simple, easy and quick method to predict pollution, although some studies tend to focus a lot on yearly production plus many are not as calibrated with observed data. Nevertheless, the regular track of the variability of the EC in the catchment might be the key for planning and managing pollution (with Best Management Practices, for instance), as its utilization does not require high levels of modeling skills. Also, it is important to state that, as observed in the analysis on this paper, each catchment has its own particularities and despite some coefficients can be similar, each study should have its own EC for management purposes.

That being said, it was shown that international studies have consistent and comparable values. As observed in the majority of the works developed, focus is on nutrients (Phosphorus and Nitrogen). However, in Brazil, values vary by many orders of magnitude, especially the ones from FCTH, (2017). As mentioned, the main reason is due the lack of sanitation infrastructure on this area. The unexpected quickly growth on urban areas with no planning or structure has been the major cause of pollution in surface waters in large cities, as São Paulo and it is possible to see the results of this problem in Pinheiros and Tietê Rivers. Finally, other reason might address to the fact that only recently the issues concerning nonpoint pollution is being paid attention, especially in Brazil and in developing countries. That calls attention to the importance of the studies on nonpoint pollution prediction.

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REFERENCES

ARC, A. R. C. (2016). *"Georgia Stormwater Management Manual."* Retrieved November, 18, 2020.

Baptista, M., N. Nascimento and S. Barraud (2005). "*Compensatory techniques in urban drainage (Técnicas compensatórias em Drenagem Urbana)*, Brazilian Association of Water Resources." Porto Alegre.

Beck, M. (2005). *"Vulnerability of water quality in intensively developing urban watersheds."* Environmental Modelling & Software 20(4): 381-400.

Borah Deva, K., E. Ahmadisharaf, G. Padmanabhan, S. Imen and M. Mohamoud Yusuf (2019). *"Watershed Models for Development and Implementation of Total Maximum Daily Loads."* Journal of Hydrologic Engineering 24(1): 03118001.

D'Arcy, B. and A. Frost (2001). *"The role of best management practices in alleviating water quality problems associated with diffuse pollution."* Science of The Total Environment 265(1-3): 359-367.

Eiger, S., C. H. Aranha, M. C. d. A. Gomes, L. Perez and A. Bueno Neto (1999). *"Modelagem matemática de cargas difusas na bacia do Guarapiranga, São Paulo."* XIII Simpósio Brasileiro de Recursos Hídricos, Belo Horizonte.

FCTH (2009). "*Avaliação da Qualidade das Águas do Sistema Pinheiros-Billings em função da operação do protótipo da flotação."* Relatório Final. mar. M. T. L. Barros, M. F. A. Porto, J. R. S. Martins et al. São Paulo, SP, Fundação Centro Tecnológico de Hidráulica. 4.

Hatt, B. E., T. D. Fletcher, C. J. Walsh and S. L. Taylor (2004). *"The Influence of Urban Density and Drainage Infrastructure on the Concentrations and Loads of Pollutants in Small Streams."* Environmental Management 34(1).

Johnes, P. J. (1996). *"Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach."* Journal of Hydrology 183(3-4): 323-349.

Morihama, A. C. D., C. Amaro, E. N. S. Tominaga, L. F. O. L. Yazaki, M. C. S. Pereira, M. F. A. Porto, P. Mukai and R. M. Lucci (2012). *"Integrated solutions for urban runoff pollution control in Brazilian metropolitan regions."* Water Science and Technology 66(4): 704-711.

Novotny, V. (1994). *"Water quality: prevention, identification and management of diffuse pollution*", Van Nostrand-Reinhold Publishers.

NOVOTNY, V. (2002). *"Water Quality: Diffuse Pollution and Watershed Management.*" New York, NY, Wiley.

Novotny, V. (2005). *"Diffuse Pollution from Agriculture in the World."*

Righetto, A. M., K. M. Gomes and F. R. S. Freitas (2017). *"Poluição difusa nas águas pluviais de uma bacia de drenagem urbana.*" Engenharia Sanitaria e Ambiental 22: 1109-1120.

Shrestha, S., F. Kazama, L. T. H. Newham, M. S. Babel, R. S. Clemente, H. Ishidaira, K. Nishida and Y. Sakamoto (2008). *"Catchment scale modelling of point source and non-point source pollution loads using pollutant export coefficients determined from long-term in-stream monitoring data."* Journal of Hydro-environment Research 2(3): 134-147.

SMA, S. d. M. A. d. E. d. S. P. (1998). "*Avaliação da Poluição por Fontes Difusas Afluentes ao Reservatório Guarapiranga"*. P. Engenharia. São Paulo, SMA, Secretaria do Meio Ambiente do Estado de São Paulo.

SSRH, S. D. S. E. R. H. (2016). "*Avaliação de poluição proveniente de fontes difusas na área de influência do sistema produtor alto tietê – SPAT – reservatórios Taiaçupeba, Jundiaí, Biritiba, Ponte nova e Paraitinga"*. C. P. FCTH. São Paulo. 1